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Autumn Vegetable Response to Residual Herbicides Applied the Previous Spring under Low-Density Polyethylene Mulch

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Field studies were conducted in 2002 and 2005 to evaluate autumn vegetable tolerance to residual herbicides applied the previous spring under low-density polyethylene (LDPE) mulch. Spring applications of 1.12 kg/ha *S*-metolachlor, 0.027 kg/ha halosulfuron, 0.28 kg/ha sulfentrazone, and 1.12 kg/ha *S*-metolachlor plus 0.027 kg/ha halosulfuron were made under LDPE mulch in March of each year and included a nontreated control. After removal of the spring crop, vegetables were planted the following August. Seeded and transplanted squash, seeded cucumber, transplanted eggplant, and transplanted cabbage were evaluated. Injury to eggplant, cucumber, and transplanted and seeded squash ranged from 8 to 16% for halosulfuron, sulfentrazone, and *S*-metolachlor plus halosulfuron in 2002, but no injury was observed in 2005. Cabbage injury was less than 5% for any herbicide treatment either year. There were no differences for cabbage biomass for three harvests for any herbicide treatment relative to the nontreated control. Vine length for cucumber and transplanted squash was significantly reduced by sulfentrazone relative to the nontreated control. Eggplant yield for the first harvest was significantly reduced by sulfentrazone as compared with the nontreated control in 2002 but not in 2005. To avoid injury to rotational crops, growers should read all herbicide labels when considering spring herbicide applications under LDPE mulch when autumn vegetable plantings are part of their production scheme to ensure successful crop production.
Nomenclature: Halosulfuron; *S*-metolachlor; sulfentrazone; cabbage, *Brassica oleracea* L.; cucumber, *Cucumis sativus* L.; eggplant, *Solanum melongena* L.; squash, *Cucurbita pepo* L.
Key words: Carryover, susceptibility to herbicides, crop biomass, methyl bromide alternatives.

The use of LDPE mulch has become standard for production of many vegetables in the southeastern United States (Motis et al. 2003; Patterson 1998; Webster et al. 2001). Most of the LDPE mulch is laid for spring vegetable production and the beds are reused for a second crop in the autumn and potentially a third crop the following spring. Spring vegetables grown after LDPE mulch fumigation include pepper (*Capsicum annuum* L.), tomato (*Lycopersicon esculentum* L.), squash, and eggplant. A second autumn crop often includes cabbage, eggplant, cucumber, or squash. This second crop is either seeded or transplanted directly into the existing LDPE-covered beds formed after the previous spring fumigation (Webster et al. 2001). This allows two crops to be grown in one calendar year and minimize expenses associated with polyethylene mulch and drip-tape irrigation by spreading their costs over multiple crops.

Currently, spring-prepared LDPE-covered beds depend on methyl bromide (MBr) for season-long weed and pest control (Locascio et al. 1997; Webster et al. 2001). Although limited amounts of MBr will be available through 2006 because of a critical-use exemption, the eventual elimination of MBr availability is nearing. Alternative fumigants are available for the control of disease and nematodes (Csinos et al. 1997; Gilreath et al. 2004; Locascio et al. 1997; Norton 2004), but weed control is more challenging (Gilreath and Santos 2004a; Stiles et al. 1999). Therefore, combinations of fumigants and herbicides will be required to replace MBr (Gilreath and Santos 2004b).

Potential alternative MBr fumigant options include chloropicrin, 1,3-dichloropropene, metam sodium, and combinations of these fumigants. Previous research noted that fumigant alternatives provide substantially less weed control than MBr, particularly with *Cyperus* species (Gilreath and Santos 2004a, 2004b; Webster et al. 2001). Herbicides will likely be part of systems adapted to replace MBr to achieve full-season control (Gilreath et al. 2004; Gilreath and Santos 2004b; Manning and Fennimore 2001).

Considering that *Cyperus* species are the most troublesome weeds in vegetable production in many states (Webster 2006), herbicides integrated into the LDPE mulch–fumigant system must control these species. Halosulfuron (Vencill et al. 1995), sulfentrazone (Wehtje et al. 1997), and metolachlor (Obrigawitch et al. 1980) all have *Cyperus* species activity and are either registered or pending registration for use under LDPE mulch in Georgia pepper and tomato (Culpepper 2005).

With the removal of MBr, herbicides will become a major component of weed management in vegetable crops. There have been many factors that have minimized herbicide use in vegetable production since (1) MBr was an effective weed management tool, (2) minor crop registration was too costly for companies to undertake alone, and (3) herbicides represented too great a risk for companies to assume alone given the high cost of vegetable production and the low return for their investment. Changes are continuing to occur as MBr is on the brink of elimination and the Interregional Project 4 is assisting to register herbicide minor-use crops. The major issue is that there has been limited data about the effects of residual herbicides in multicrop LDPE vegetable production. Thus, a study was initiated to determine autumn vegetable response to residual herbicides following spring application of halosulfuron, metolachlor, and sulfentrazone in combinations with soil fumigants applied under LDPE mulch.

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Materials and Methods

Experiments were conducted in 2002 and 2005 at the Ponder Research Station at TyTy, GA. Soil type was Tifton loamy sand (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) with 88% sand, 8% silt, 4% clay, and 1.3 and 0.9% organic matter and pH 6.0 and 6.2 in 2002 and 2005, respectively. The soil was disk-harrowed and moldboard-plowed 25–30 cm deep. Single beds (0.82 m wide, 22.9 m long, and 15 cm high) were established with a bed shaper. All herbicide treatments were applied in March of 2002 and 2005. Herbicides were applied with a CO_2-pressurized sprayer calibrated to deliver 187 L/ha at 210 kPa to a prepared bed. These areas were then fumigated and immediately covered with black 32-µm-thick (1.25 ml) LDPE mulch over each bed. A single drip irrigation tube with emitters spaced 30 cm apart with a flow rate of 30 ml/min was placed in the center of the bed under the polyethylene mulch for application of water and fertilizer.

In 2002 a spring fumigant study was conducted with five herbicide combinations. Herbicide treatments were 1.12 kg/ha *S*-metolachlor, 0.027 kg/ha halosulfuron, 0.28 kg/ha sulfentrazone, and 1.12 kg/ha *S*-metolachlor plus 0.027 kg/ha halosulfuron and a nontreated control. The spring pepper planting was terminated in July 2002, plant debris removed, and then the LDPE painted white with latex paint to reduce heat buildup under the mulch. In 2002, the experimental design was a randomized complete block replicated 10 times. In 2005 MBr was spring-applied with the herbicide treatments previously described and the study was repeated. The replicated watermelon planting was terminated in June 2005, plant debris removed, and then the LDPE painted white with latex paint. In 2005 there were three replications per treatment. Herbicide-treated plots included a single row of vegetables on a bed 0.82 m wide by 4.6 m long, with stand based on University of Georgia recommendations for vegetables (Anonymous 2005). For the 2002 and 2005 studies, beds were maintained weed free for the entire season by hand-weeding when necessary.

Commercial cabbage, squash, cucumber, and eggplant cultivars commonly grown in the southeastern United States during the autumn were selected. Vegetables cultivars evaluated for tolerance to spring-applied residual herbicide were the seeded and transplanted squash 'Prelude II', seeded cucumber 'Thunder', transplanted eggplant 'Santana', and transplanted cabbage 'Rio Verdi'. All transplants were grown in a greenhouse in commercial potting media using plastic bedding trays for 4 wk before transplanting. Transplanted eggplant, transplanted and seeded squash, seeded cucumber, and transplanted cabbage were established in the field by either hand transplanting (7.5 cm deep into soil) or seeding (2.54 cm deep into soil) in August of 2002 and 2005. The final comparisons for stand were based on the nontreated control.

Irrigation was applied as needed by drip tape, and fertilizer was applied on the basis of University of Georgia recommendations for vegetables (Anonymous 2005). Insects and plant diseases were monitored and sprayed when necessary (Anonymous 2005).

Crop injury and population density were evaluated for all crops. Crop injury, based on visible stunting and yellowing, was rated on a scale of 0 (no injury) to 100% (crop death) and stand counts were evaluated 3 wk after planting. Crop height was evaluated for cabbage and eggplant 2 wk after transplanting. Vine length for transplanted and seeded squash and cucumber were measured 3 wk after planting. For the 2002 study, fresh-weight plant biomass was measured by harvesting all plants from a single plot for transplanted and seeded squash at 5 wk after planting, and for cucumber at 7 wk after planting. For the 2005 study, transplanted and seeded squash fruit biomass was de-

Table 1. Carryover injury to 2002 autumn-planted vegetables as affected by spring herbicide application in peppers.

Herbicide treatment	Rate	Transplant[a] Eggplant	Transplant[a] Cabbage	Transplant[a] Squash	Seeded Squash	Seeded Cucumber
	kg/ha	%				
Nontreated control		0	0	0	0	0
S-Metolachlor	1.27	11	1	15	12	6
Halosulfuron	0.027	9	0	14	9	11
Sulfentrazone	0.28	12	5	7	8	15
S-Metolachlor plus halosulfuron	1.27 + 0.027	7	2	11	8	16
LSD (0.05)		NS[b]	4	NS	NS	NS

[a] Injury rating 20 d after planting.

[b] Abbreviation: NS, not significant.

Table 2. Plant height and vine length for autumn-planted vegetables as affected by spring herbicide application under polyethylene mulch.

		Transplant					Seeded			
			Cabbage		Squash		Squash		Cucumber	
Herbicide treatment	Rate	Eggplant[a]	2002	2005	2002	2005	2002	2005	2002	2005
	>kg/ha	cm/plant								
Nontreated control		24	33	17	16	35	14	18	122	109
S-Metolachlor	1.27	26	34	16	16	35	15	17	112	87
Halosulfuron	0.027	24	32	16	15	38	14	24	115	104
Sulfentrazone	0.28	24	33	17	14	30	14	16	79	73
S-Metolachlor plus halosulfuron	1.27 + 0.027	25	32	16	16	38	14	17	123	100
LSD (0.05)		NS[b]	NS	NS	2	NS	NS	NS	27	32

[a] No year-by-treatment interaction for eggplant height was noted so data for this variable were combined for 2002 and 2005.

[b] Abbreviation: NS, not significant.

Table 3. Plant biomass for autumn-planted vegetables as affected by spring herbicide application under low-density polyethylene mulch.

		Cabbage biomass							
		First harvest		Second harvest		Third harvest		Cucumber vegetative biomass	
Herbicide treatment	Rate	2002	2005	2002	2005	2002	2005	2002	2005
	kg/ha	g/plant							
Nontreated control		360	102	820	404	1,100	1128	238	126
S-Metolachlor	1.27	340	298	940	472	1,150	726	215	95
Halosulfuron	0.027	520	246	1170	352	1,510	786	247	130
Sulfentrazone	0.28	480	282	870	502	1,150	882	230	112
S-Metolachlor plus halosulfuron	1.27 + 0.027	440	142	960	400	1,230	452	170	145
LSD α=0.05		110	NS[a]	170	NS	240	NS	NS	NS

[a] Abbreviation: NS, not significant.

termined by hand-harvesting the entire plot when the first mature fruit was detected, three times a week from late August to October. Fresh-weight plant biomass for cabbage was determined by harvesting five consecutive plants from each plot at 10, 12, and 14 wk after planting. Eggplant fruit was hand-harvested from the entire plot, when the first mature fruit was detected, on a weekly basis beginning the first week of October through November of each test for a total of seven harvests. Eggplant fruit was harvested when it was at least 15 cm in length.

Vegetable injury, stand, heights, vine lengths, plant and fruit biomass, and eggplant fruit number and yield (kg/ha) on an individual harvest basis, and total for the season, were subjected to ANOVA. Data were combined for analysis to test for year and treatment interactions. Treatment means were separated using the general linear model LSD test at $P \leq 0.05$.

Results and Discussion

No year-by-treatment interaction for eggplant height was noted so data for this variable were combined. For all other variables, significant treatment-by-year interactions prevented the combining of data across the 2002 and 2005 test.

There were no significant differences in plant stand either year for transplanted eggplant, cabbage, or squash (data not shown). Stand for seeded squash and cucumber also was not different from their respective nontreated controls in either year (data not shown).

In 2002 visual injury in the form of stunting and yellowing of eggplant was 7 to 12% 20 d after transplanting, but this injury was not different from the nontreated control (Table 1). This injury was transient and not observed later in the season as plants matured. Cabbage transplants exhibited similar stunting injury in 2002. Sulfentrazone injury to cabbage was significant at 5% that year but was temporary (Table 1). Smart et al. (2001) similarly noted temporary early-season POST injury due to sulfentrazone on cabbage. Al-Khatib et al. (1995) reported slight injury to cabbage grown for seed production from *S*-metolachlor PRE but seed yield was not affected. There was no visual injury to eggplant or cabbage in 2005 (data not shown).

Transplanted and seeded squash injury ranged from 7 to 15% in 2002 but was not significantly different from the nontreated control (Table 1). For that same test, halosulfuron and *S*-metolachlor injury were 14 and 15% for transplanted and 9 and 12% for seeded squash, respectively. Additionally, cucumber injury was 6 to 16% but again was not different from the nontreated control. Previous research has indicated that cucurbits exhibited halosulfuron rate response injury when applied with the crop (Webster et al. 2003). In a carryover study, autumn-applied sulfentrazone injured spring-planted cucumber 30% (Particka and Zandstra 2004). No injury was reported for cucumber as part of a rotation for residual metolachlor (Gilreath et al. 2004). These data indicate that residual *S*-metolachlor, halosulfuron, and sulfentrazone spring-applied under polyethylene mulch

Table 4. Autumn transplanted and seeded squash fruit yield as affected by spring herbicide application under low-density polyethylene mulch in 2005.

		Fruit numbers				Fruit biomass			
		First harvest		Season total		First harvest		Season total	
Herbicide treatment	Rate	Transplanted	Seeded	Transplanted	Seeded	Transplanted	Seeded	Transplanted	Seeded
	kg/ha	Fruit/plant				kg/plant			
Nontreated control		0.2	0.7	9.9	6.0	0.02	0.08	1.2	0.8
S-Metolachlor	1.27	0.1	0.6	10.6	5.9	0.01	0.06	1.3	0.8
Halosulfuron	0.027	0.1	0.3	10.8	4.3	0.01	0.04	1.4	0.6
Sulfentrazone	0.28	0.1	0.4	9.3	5.8	0.01	0.04	1.3	0.8
S-Metolachlor plus halosulfuron	1.27 + 0.027	0.1	0.5	11.0	5.3	0.01	0.06	1.4	0.7
LSD α = 0.05		NS[a]	NS	NS	NS	NS	NS	NS	NS

[a] Abbreviation: NS, not significant.

Table 5. Autumn eggplant fruit production and yield as affected by spring herbicide application under low-density polyethylene mulch.

		Fruit numbers				Fruit biomass			
		First harvest		Season total		First harvest		Season total	
Herbicide treatment	Rate	2002	2005	2002	2005	2002	2005	2002	2005
	kg/ha	Fruit/plant				kg/plant			
Nontreated control		0.6	0.3	5.1	5.0	0.3	0.1	2.2	2.4
S-Metolachlor	1.27	0.5	0.4	5.0	5.1	0.3	0.1	2.2	2.5
Halosulfuron	0.027	0.7	0.3	5.3	4.9	0.3	0.1	2.2	1.9
Sulfentrazone	0.28	0.3	0.3	4.7	4.9	0.2	0.1	2.0	1.9
S-Metolachlor plus halosulfuron	1.27 + 0.027	0.7	0.3	5.4	4.9	0.3	0.1	2.3	2.1
LSD $\alpha = 0.05$		0.2	NS[a]	NS	NS	0.1	NS	NS	NS

[a] Abbreviation: NS, not significant.

can cause injury to fall-planted vegetables. There was no injury for the cucumber or transplanted or seeded squash in 2005 (data not shown).

Height of eggplant and cabbage were not affected by *S*-metolachlor, halosulfuron, sulfentrazone, or *S*-metolachlor plus halosulfuron (Table 2). Vine length for transplanted squash was significantly reduced by sulfentrazone relative to the nontreated control in 2002. However, seeded squash was not affected in either year and transplanted squash was not affected in 2005 by any treatment. Cucumber exhibited significant 33 to 35% vine reduction (73 to 79 cm) from residual sulfentrazone as compared with the nontreated control (109 to 122 cm). These injury and vine length data indicate that cucumber should not be seeded in autumn following a spring application of suflentrazone.

Cabbage plant biomass at each harvest was not affected by halosulfuron, sulfentrazone, or *S*-metolachlor plus halosulfuron in 2002 and 2005 (Table 3). *S*-Metolachlor-treated cabbage biomass averaged 340 g per plant for first harvest. By the second and third harvest cabbage biomass for residual *S*-metolachlor was comparable with all other treatments in 2002. Smart et al. (2001) noted sulfentrazone POST injury on cabbage but this was transient and did not adversely affect yield. Sulfentrazone currently has a registration for seeded and transplanted processing cabbage (Anonymous 2006).

Transplanted squash in 2002 (data not shown) and seeded cucumber in 2002 and 2005 plant biomass harvest were not significantly affected by any herbicide treatment (Table 3). However, these data did not reflect the visual injury and reduced vine lengths previously described for sulfentrazone and therefore should not be used as an indicator of potential carryover.

Seeded and transplanted squash fruit yield for 2005 for the first and cumulative harvest were similar to the nontreated control for all herbicide treatments (Table 4). Transplanted squash had 11 harvests while seeded squash had 8.

Eggplant fruit number and yield for single or cumulative harvests were similar to or greater than the nontreated control for *S*-metolachlor, halosulfuron, and *S*-metolachlor plus halosulfuron (Table 5). These responses indicated that these residual herbicides did not adversely affect eggplant planted as a second crop in polyethylene production in Georgia. Eggplant yield in terms of fruit number (0.3 fruit/plant) and biomass (0.2 kg/plant) was significantly reduced by sulfentrazone relative to the nontreated control for the first harvest in 2002, but not in 2005 (Table 5). The 2002 injury that occurred in early-season ratings along with plant height reduction resulted in reduced first-harvest quantity and biomass. For the season total, eggplant fruit number and kg/plant averages for sulfentrazone were similar to the other treatments, but numerically the least in 2002. Sulfentrazone currently has a pending registration for eggplant (Anonymous 2006).

These results indicate that in terms of tolerance to residual activity, cabbage, eggplant, squash, and cucumber were tolerant to halosulfuron. Cabbage and eggplant were tolerant to *S*-metolachlor. Squash and cucumber exhibited injury from sulfentrazone. Growers should use caution when considering autumn plantings of seeded cucumber, as data indicated that this species was not tolerant to spring-applied sulfentrazone. Further research should be conducted with sulfentrazone for fresh-market cabbage, eggplant, and yield of seeded cucumber. The impending loss of MBr for soil sterilization necessitates the evaluation of alternative weed control options in U.S. vegetable production.

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